Heating operation with an awareness of the energy system

- *The case of model predictive control*

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CITIES workshop on Integration of prosumer buildings in energy systems
06/04/2018, DTU, Kgs. Lyngby

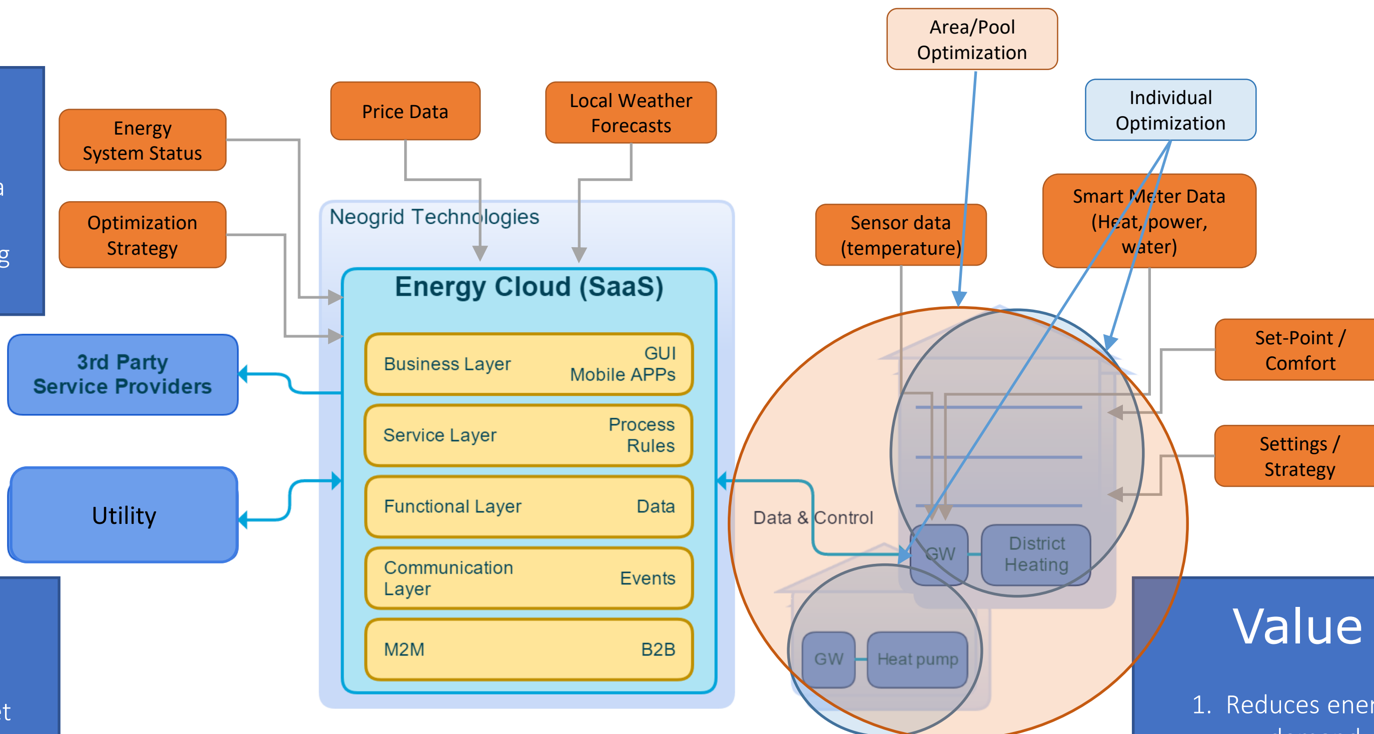
Neogrid Technologies ApS

- Development of energy optimisation concepts since 2010
- Intelligent energy visualisation, monitoring and control
- Cloud-based large scale system for users, building administrators, utilities, and third party actors (e.g. heat-pump manufacturers) for control of energy use
  - *Advanced analysis- and control tools, using dynamic forecasts of building energy usage and flexibility – based upon thermodynamical models*
  - *Advanced control after weather forecast*
  - *Floor heating control*
  - *Optimisation of operation with alarms on anomalies*
  - *Comfort optimisation*
  - *Energy savings*
- Large scale monitoring allowing optimisation of heat-pump and heating operation at individual and aggregate level
  - *Reducing energy use and costs*
  - *Providing the energy flexibility of the loads to the energy market*

Our platform for Intelligent Energy Management

Value

1. Comprehensive data overview
2. Performance tracking



Value

1. Load Shift / Market
2. Load forecast for aggregate

Value

1. Reduces energy demand
2. Improves indoor climate

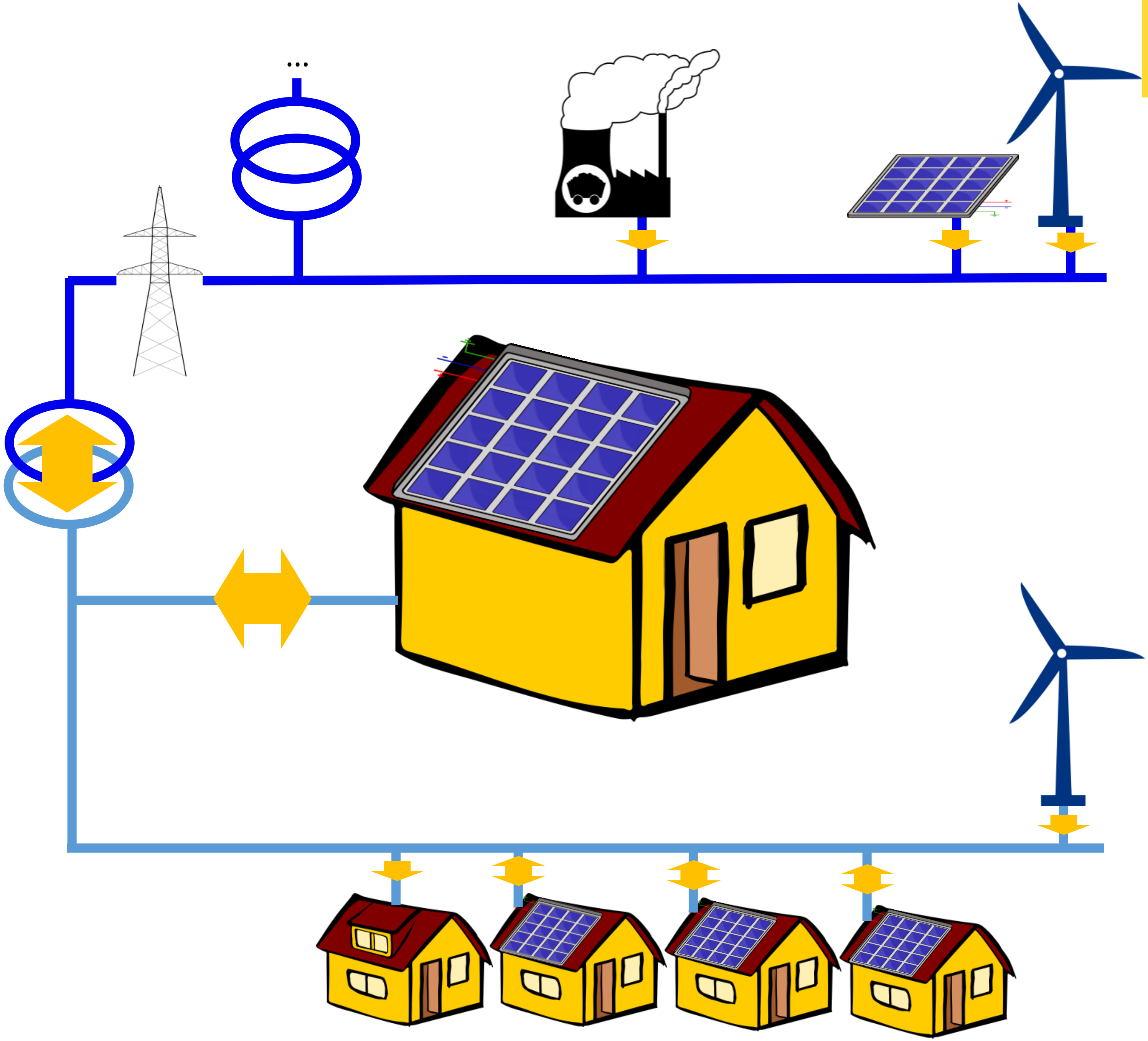
Outline

I. Context

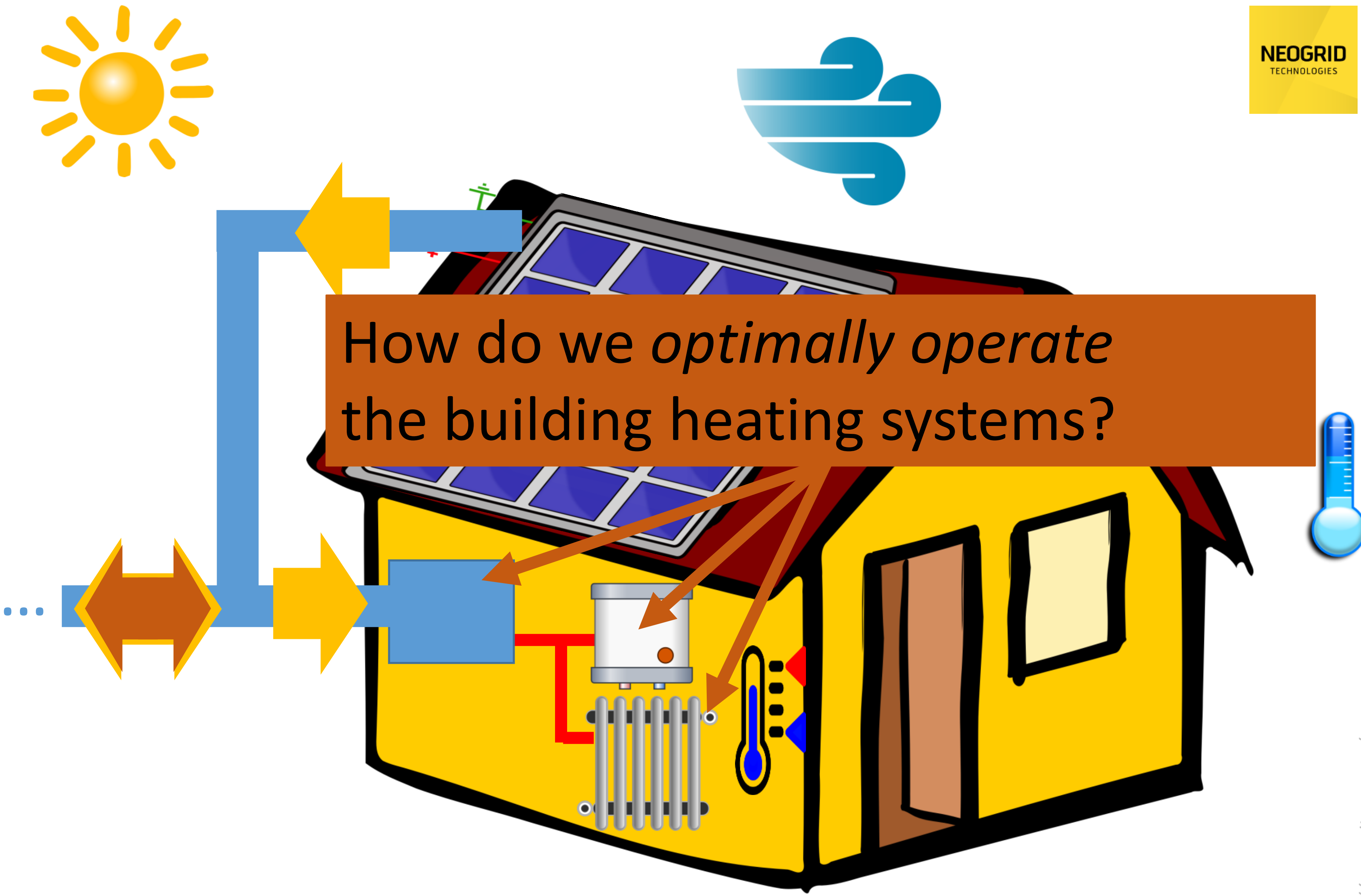
II. Decision making using model predictive control

III. Use cases of MPC in practise

IV. Open questions and discussion
(ca. 10 minutes)



[Cliparts] https://openclipart.org/



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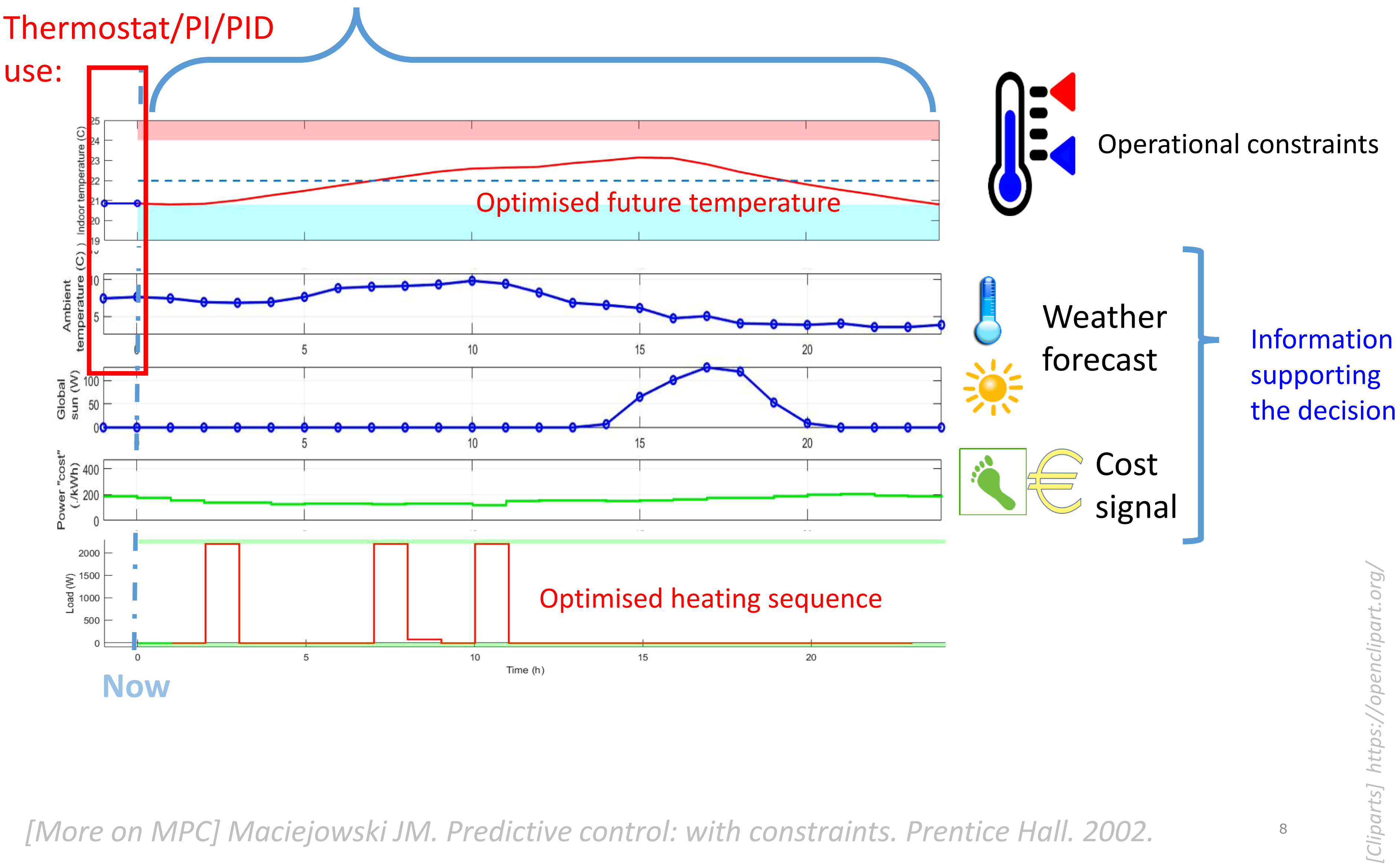
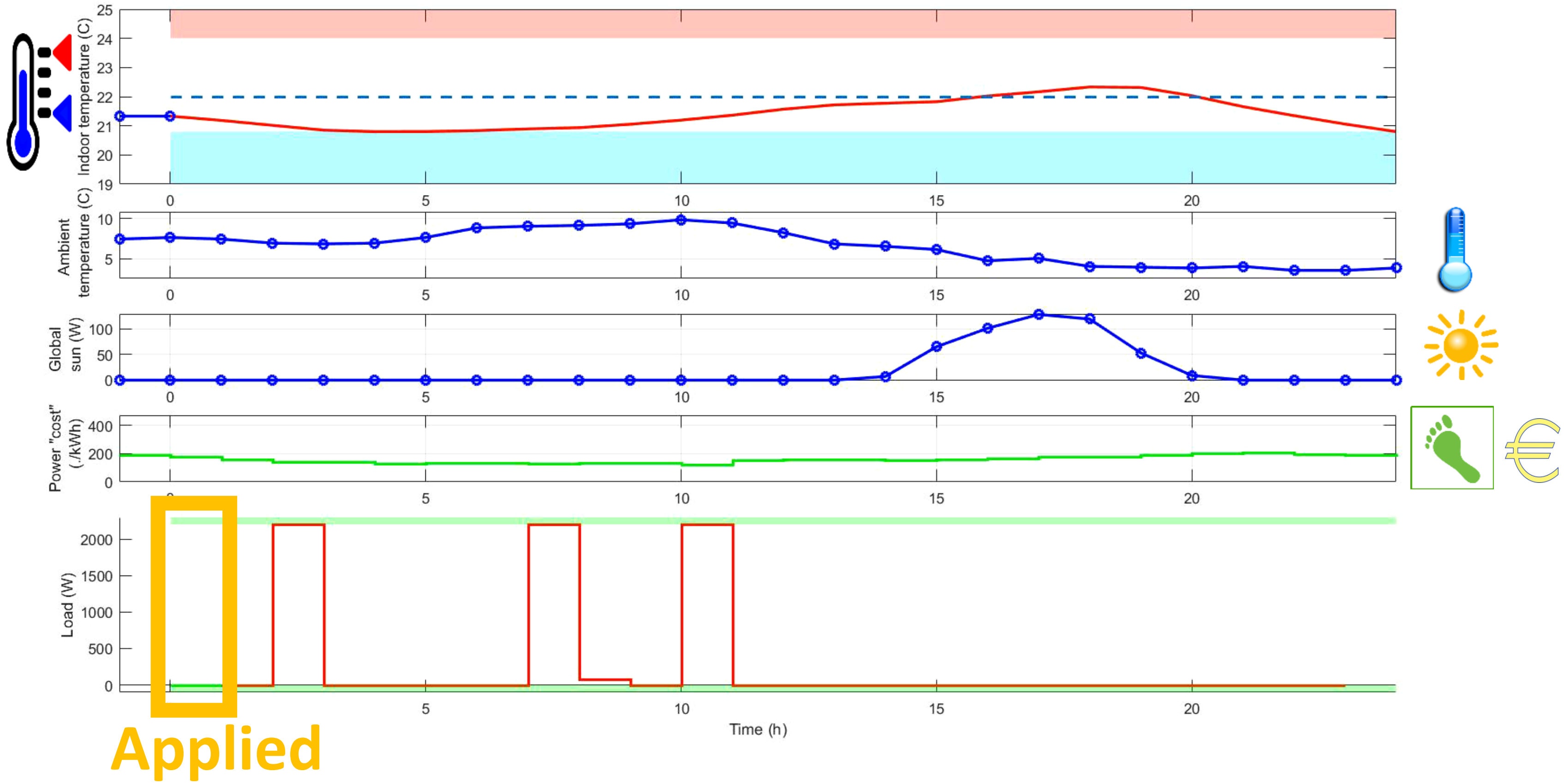
Decision making using Model Predictive Control (MPC)

MPC optimises operation based upon expected future behaviour



[More on MPC] Maciejowski JM. Predictive control: with constraints. Prentice Hall. 2002.

MPC operates in receding horizon



[Receding horizon] Jørgensen JB. Moving Horizon Estimation and Control 2004. PhD thesis, DTU

[Cliparts] https://openclipart.org/

MPC relies upon mathematical optimisation

$$\min \sum_{i=1}^{N_c} \boxed{F(X[i], U[i], i) \quad \text{Objective function}}$$

$$s.t.$$

$$\forall i \in [1, N_c], \boxed{\begin{aligned} X[i+1] &= AX[i] + B_{\mathrm{U}}U[i] + B_{\mathrm{V}}V[i] \\ X[1] &= X_0 \quad \text{Modelled system dynamics} \end{aligned}}$$

$$\boxed{\begin{aligned} X_{inf} &\leq X[i+1] \leq X_{sup} \\ U_{inf} &\leq U[i] \leq U_{sup} \quad \text{Operational constraints} \end{aligned}}$$

[More details on MPC] Afram, A. & Janabi-Sharifi, F., Theory and applications of HVAC control systems – A review of model predictive control (MPC), 2014, Building and Environment, 72, pp 343–355

Use-cases of MPC in practise

MPC strategies for grid connected **con-**sumers

Minimise

- Energy consumption
- Energy cost *(with dynamic price)*
- Indirect CO_2 emissions
- Consumption at peak times in the grid

Interacting with the energy system
(others are building-centric)

Maximise

- COP of heat-pump
- Thermal comfort

(!) Trade-offs arise between of these strategies

[Strategies] Clauß et al. Control strategies for building energy systems to unlock demand side flexibility – A review. Building Simulation Conference 2017, San Francisco. http://researchrepository.ucd.ie/handle/10197/9016

[Tradeoff CO2 / price] Knudsen, Petersen. Demand response potential of model predictive control of space heating based on price and carbon dioxide intensity signals. Energy and Buildings 2016;125:196–204.

[Tradeoffs renewables/CO2/energy/comfort] Vogler-Finck et al. Comparison of strategies for model predictive control for home heating in future energy systems. IEEE PowerTech, Manchester: IEEE; 2017

MPC strategies for grid connected **pro-**sumers

Minimise

- Energy curtailed
- Energy imports
- Energy cost *(with dynamic import/export prices)*
- Indirect CO_2 emissions *(with dynamic emissions for imports)*
- Consumption/export at times of congestions on the grid
- Deviation from a production/consumption reference

[Review] Clauß et al. Control strategies for building energy systems to unlock demand side flexibility – A review. Building Simulation Conference 2017, San Francisco. http://researchrepository.ucd.ie/handle/10197/9016

Different MPC have different technology readiness levels (TRL)

Demonstrated on real occupied buildings
- Energy optimisation in single family homes* *[1]*
- Spot price optimisation for pools of buildings*
- Energy and price optimisation in office buildings *[2,3]*

Demonstrated in simulation studies
- CO_2 optimisation
- Maximise self-consumption
- Minimise curtailed power *[4]*

*: Neogrid has field experience on these applications

[1] Lindelöf D et al. Field tests of an adaptive, model-predictive heating controller for residential buildings. Energy and Buildings 2015
[2] Opticontrol (http://www.opticontrol.ethz.ch/)
[3] De Coninck R, Helsen L. Practical implementation and evaluation of model predictive control for an office building in Brussels. Energy and Buildings 2016
[4] Salpakari J, Lund P. Optimal and rule-based control strategies for energy flexibility in buildings with PV. Applied Energy 2016

MPC has advantages and drawbacks

Potential benefits*
- Reducing energy consumption
- Improved comfort
- Load shifting (peak shaving, higher self consumption, integration of renewables…)

Drawbacks*
- Labour intensive (modelling is hard, development of the framework is costly)
- Complexity (specific skills required, troubleshooting is harder)
- Computationally intensive

(*: Compared to thermostat/PI control)

[Reviews]
1- Afram, Janabi-Sharifi. Theory and applications of HVAC control systems - A review of model predictive control (MPC). Building and Environment 2014
2- Fischer, Madani. On heat pumps in smart grids: A review. Renewable and Sustainable Energy Reviews 2017
3- Shaikh et al. A review on optimized control systems for building energy and comfort management of smart sustainable buildings. Renewable and Sustainable Energy Reviews 2014

Take home messages on MPC

- Model predictive control (MPC) uses **optimisation** in **receding horizon**

- MPC requires a **numerical model** (built with experimental data)

- MPC can optimise according to different **strategies**
  (e.g. minimise peak load, CO_2 emissions, imports of power, cost)

- MPC can be applied both at **building-** and **neighbourhood-** level

Open questions and discussion

Questions on the presentation?

?

Which costs signals should we use in the MPC?

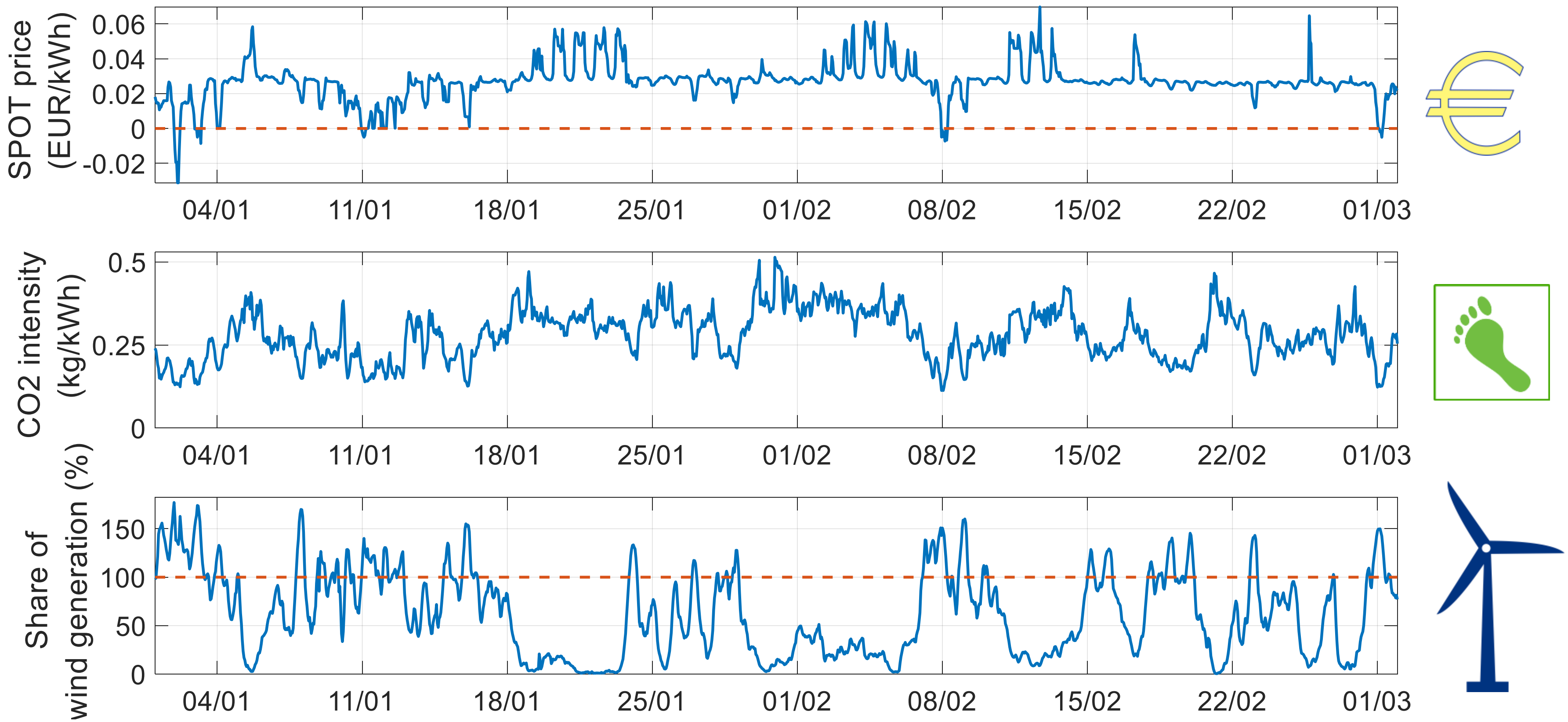
Possibilities are (among others):

- Signals from the transmission level
  - Power price (Spot, imbalance)
  - System load
  - CO_2 intensity (average or marginal)

- Signals from the local level
  - Load on the local system

- Signals from the building
  - Local production

An example of cost signals from the transmission grid side



Combination is possible, e.g. [1]

$$S_{\mathrm{EN}}[k] = \alpha_{\mathrm{p}} \frac{S_{\mathrm{RTP}}[k]}{< S_{\mathrm{RTP}} >} + \alpha_{\mathrm{CO2}} \frac{S_{\mathrm{CO2}}[k]}{< S_{\mathrm{CO2}} >} + \alpha_{\mathrm{load}} \frac{S_{\mathrm{load}}[k]}{< S_{\mathrm{load}} >} + \alpha_{\mathrm{PSO}} \frac{S_{\mathrm{PSO}}[k]}{< S_{\mathrm{PSO}} >}$$

Data from the project "Styr din Varmepumpe" (https://styrdinvarmepumpe.dk/)

[Cost function] M. D. Knudsen, S. Petersen, Demand response potential of model predictive control of space heating based on price and carbon dioxide intensity signals, Energy and Buildings 125 (2016) 196–204

[Cliparts] https://openclipart.org/

Which (business) models should we be building?

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Control structures

- Aggregators:
    - With *direct* control of loads/production?
    - With *indirect* control of loads/production?

- Con/Prosumer level with public data
    - Decentralised decision making at consumer/prosumer level?

Revenue
- Who will benefit from this?
- How do we build *fair* reward mechanisms between actors?

Blocking points

Comparing storage or load management ?

	Load management (e.g. with MPC)	Storage (e.g. home battery)
Pros	No need for new infrastructure Comparatively cheap	Available year round
Cons	Available only during the heating season Risk of interfering with user actions	Costly Need to invest in infrastructure

Thank you

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